Optimized Performance GaAs-Based Diode Lasers: Reliable 800-nm 125W Bars and 83.5% Efficient 975-nm Single Emitters

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GaAs-based high power diode bars produce wavelengths in the range of 780 to 980 nm and are widely used for pumping a broad range of rare earth doped solid-state lasers. As the markets for these laser systems mature, diode lasers that operate at higher power levels, greater overall efficiency, and higher reliability are in high demand. In this paper we report efficiencies of up to 83.5 % in the 9xx-nm band, continuous wave power levels over 360-Watts in the 8xx-nm band, and reliable operation at 125-Watts.

1. Introduction

The two main metrics for high power diode lasers are output power and power conversion efficiency (also often termed wall-plug), provided reliability is not compromised. Research efforts continue to push peak optical output powers and peak power conversion efficiencies[1] higher across a range of wavelengths and material systems [1,2,3]. Here we discuss recent developments in high power, reliable operation of micro-channel cooled 800-nm diode laser bars and stacked arrays. We will also review recent progress in increasing the peak efficiency 975-nm diode laser single emitters and bars. All devices discussed are constructed from the Al-In-Ga-As-P material system grown using low pressure MOCVD on GaAs substrates, and are fabricated into broad area diodes of different stripe widths and fill factors. All devices are mounted junction down onto micro-channel coolers using indium solder (for bars) and c-mounts (for single emitters). All material has high reflection coatings on the back facet and low reflection coatings on the front facet to direct the maximum amount of useful light out of the front of the device.

2. Reliable, High Power Operation of 800-nm Diode Laser Bars

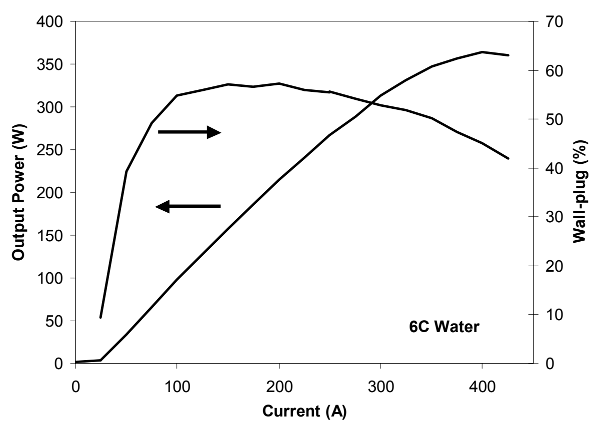

Figure 1: Peak Power in Excess of 360W is achievable from a single 800-nm diode bars at 6C cooling water temperature [1]

[1] Power conversion efficiency, *PCE*, is defined as the ratio of useful optical output power, P_{out}, to the electrical input power, IV. That is, $PCE = P_{out} \div (IV)$.

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Careful optimization of bar characteristics, solder joint and heatsink are required to reach the highest powers without compromising reliability. At power levels of 100-W and above, small defects and in-homogeneities in any of these areas can quickly lead to failure of the part. Building on thorough material studies, reliable 100W operation can be delivered, as reviewed in [1]. One crucial quality check required is to confirm that the material failure point is many times larger than the expected operation current. Figure 1 shows the measured data for a high power diode laser bar run up to 425A under CW conditions. Low temperature water (6C) and a high flow rate of de-ionized water (0.6lpm) were used. The diode bar is 1.5-mm cavity length and 80-% fill factor and operates at 800-nm. A peak power of 364-W was achieved, limited by thermal rollover, demonstrating a high performance margin. Bars to this design have run in excess of 5000 hours without failure at 100-W per bar, as reviewed in [1].

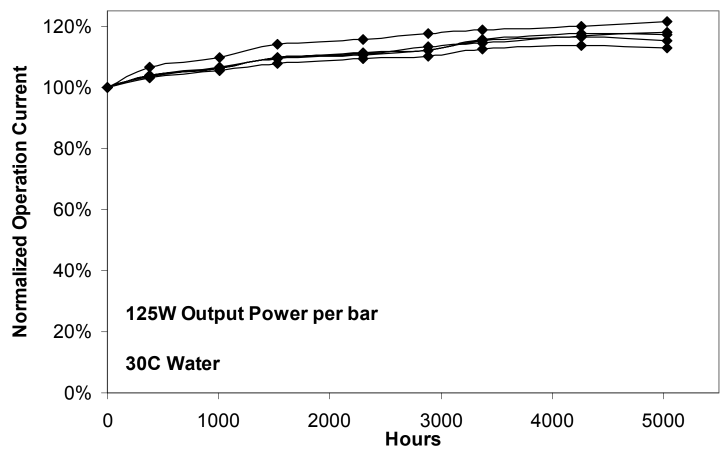

Figure 2: High power 800-nm bars operate reliably at 125W output per bar

Building on this performance, further optimization of material quality has enabled even higher power reliable CW operation, as shown in figure 2. Over 5000 hours of continual operation at 125-W per bar has been demonstrated with small, saturating degradation observed.

A further important feature of high performance diode laser bars and stacks is their temperature dependence [4] – many applications require diode lasers to operate at elevated temperatures. Figure 3 shows the performance of a stack of 18 bars, operating at 25C and 40C coolant water. Minimal change is observed with increasing temperature and over 1.5kW of output is delivered at a power density in excess of 500W/cm^2. The output of each bar is collimated in the fast axis with an appropriate rod lens. The integrated spectral width of the stack remains below 2.2nm at all temperatures – comparable to the 2-nm spectral width observed in a single emitter [4]. The maximum temperature was limited by the capability of the water chiller used.

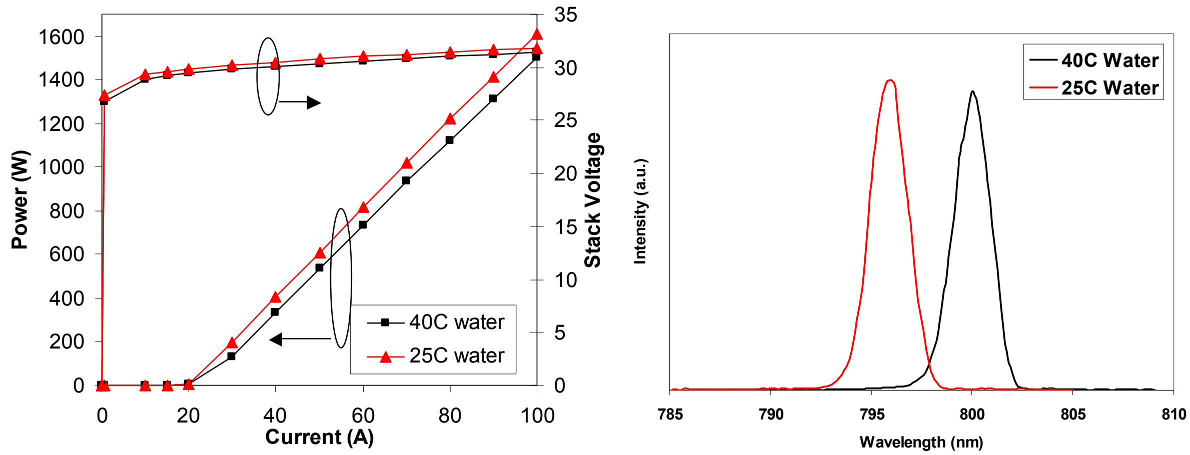

Figure 3: 18 Bar stacks of micro-channel cooled 800-nm bars deliver over 1.5kW at 40C (left), with integrated spectral width from the stack less than 2.2nm at all temperatures (right).

3. High Efficiency Operation of 975-nm Diode Laser Bars

In parallel to efforts to increase the peak reliable power of 800-nm band material, intensive studies to improve the efficiency of 975-nm diode laser bars have also been performed (as supported by DARPA under the SHEDs contract). Peak bar efficiency of up to 73% at 100W (QCW condition) and single emitter efficiency of 73% have previously been reported close to room temperature [1]. Further optimization of package and bar has enabled a peak efficiency of 72% at 70W output power under CW test conditions from a 1-cm 50% fill factor bar with 1-mm cavity length, corresponding to 35C junction temperature.

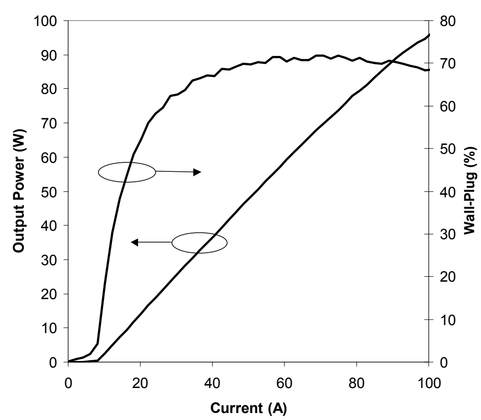

Figure 4: Under CW test conditions, full 1-cm diode laser bars reach 72% peak efficiency, corresponding to a junction temperature of 35C.

In parallel to bar and package optimization, the fundamental limits to the diode laser performance have been further investigated. The properties of the quantum well are found to critically affect the peak achievable efficiency, and design improvements to address these limitations have further increased the peak efficiency of laser material to 76% at 10C package temperature [5]. The device tested has a stripe width of 50-µm, a cavity length of 1-mm and is mounted junction down on an industry standard c-mount.

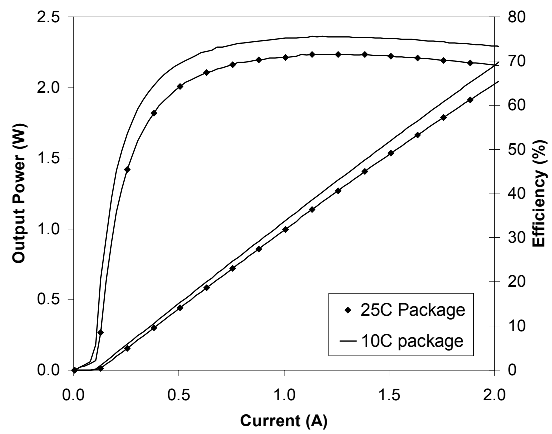

Figure 5: Peak performing 975-nm single emitters deliver up to 76% efficiency at 10C package temperature [5].

Cryogenic testing can be used to help diagnose the main limits to device performance and also shows the peak capability of high efficiency material. A single emitter mounted junction down to a copper c-mount was tested to 77K, with peak efficiency of 83.5% observed at 138K. The device selected has 200-µm stripe width, 1-mm cavity length and has a peak efficiency of 71% at 288K. Re-test of the device after cryogenic cycling showed no degradation in performance.

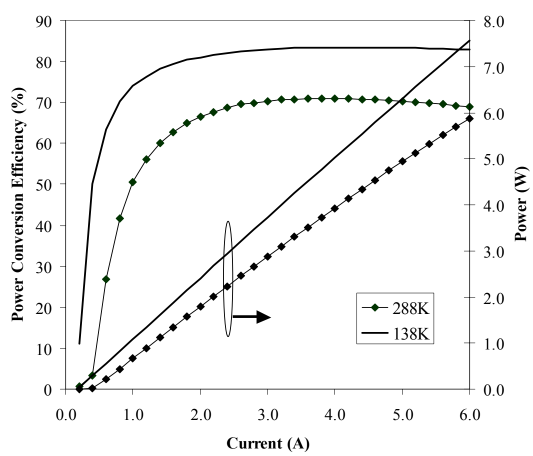

Figure 6: Testing devices to cryogenic temperatures further increases efficiency, reaching a peak of 83.5% at 138K [5].

4. Conclusions

Careful optimization of diode laser, package and solder leads to peak output powers of 364W from a 1-cm 800-nm diode laser bar and reliable operation at 125W per bar. These bars can be integrated into high power stacked arrays and deliver CW powers in excess of 1.5kW at a power density of > 500W/cm2 at water temperatures of 40C. Parallel optimization has increased the power conversion efficiency of 975-nm diode laser material. Single emitters now deliver 83.5%

at 138K package and 76% at 10C package. High power bars deliver 72% efficiency at 35C junction temperature.

5. References

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